HD 1.3 Quantity-Distances
Shorter But Still Safe

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Introduction

The UK military quantity-distances are closely related to those agreed by NATO and over the last 4 years the Science, Explosives & Testing branch of the Naval Support Command has been asked to advise on the safety of over 400 naval potential explosion sites which do not conform to the regular UK military quantity-distances.

Based on some of the experience gained in giving this advice, this paper reports how quantity-distances for Hazard Division 1.3 can be realistic and also shorter without compromising safety criteria.

Research Outline - Distances To Prevent Propagation

Following prolonged tests Jarrett (Ref 1) was able to advise distances at which propellant either in wooden boxes or unpacked and loose would not ignite when exposed to a massive propellant fire. Today the boxed distances are the Intermagazine Distances and the unpacked ones plus a margin to protect workers are the Process Building Distances.

Research Outline - Distances To Prevent Harm To People

Jarrett applied Glasstone (Ref 2) on nuclear explosions and compared nuclear thermal irradiation with that from conventional explosions of equivalent yield to justify distances to the public. In his work he explained that, "correction needs to be made for dose rate and spectral quality" and that, "The spectral emission (equivalent black body temperature of 1390◦C measured in the trials) is quite different from a nuclear fireball" but nevertheless for distances to the public "it would appear as afirst approximation that the emission from propellant fires is comparable with that for devices of the order of 200kt." Baker et al (Ref 3) recommend use of Buettner's work (Ref 4) on pain threshold for distances to people. They say, "To extrapolate the nuclear weapon data to predict radiation effects from propellant, explosive and other chemical reaction fireballs is very dangerous, as the wave lengths being transmitted are orders of magnitude different."

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Conclusions From The Research

The quantity-distances to prevent propagation remain valid but further work is indicated to justify distances to people, be they explosive workers or the public.

Problem

This further work to justify the UK Inhabited Building Distances had been delayed because of the difficulty in reconciling differences between two bodies of research into burns on human skin. One body is typified by Stoll & Greene (Ref 5) and the other by Perkins et al (Ref 6). Perkins' measurement of the heat dose needed for first degree radiation burns is much higher than that measured by Stoll & Greene. Although both sets of data can be modelled each model would produce different quantity-distances.

The reason for the difference between Perkins and Stoll & Greene is that Perkins' measurements were made using a high temperature source and the short wavelengths of the radiation means it penetrates the skin to 3mm before being absorbed. Because a large volume of skin is heated the temperature rise is small and consequently a much larger heat dose is needed to produce skin damage. Whereas Stoll & Greene used a low temperature source whose longer wavelength radiation does not penetrate the skin so the whole heat dose is absorbed by the surface cells which are more readily destroyed. Furthermore skin reflectivity varies with wavelength; 5% for long wavelengths and 60% for short.

Problem Possibly Solved

Henriques published a theory on skin burns (Ref 7) based on a form of the Arrenhius equation for irreversible chemical reaction. He concluded that skin burn occurs because of thermally induced changes in protein structure that have an activation energy of about 600 MJ/kg-mol. In general he says that skin cell destruction occurs to a depth *x* from the surface when :

EQUATION

$$\omega = 1 = \int_0^t e^{226.78 - \frac{75000}{T}} \, dt$$

where T is the temperature at depth *x* and is a function of time and ω is a function of burn injury, for example ω = 1 for complete cell destruction and ω = 0.53 for a partial thickness burn (2nd degree burn).

This equation is difficult to integrate except when T is constant which is a special case. Historically Henriques' theory had been variously adjusted to match the differing observed results but Lawton observed that if Henriques equation is adjusted to allow for penetration of radiation before absorption it gives accurate predictions of skin temperature and burn damage

regardless of the nature of the heat source.

To overcome the difficulty integrating Henriques' equation he computed skin temperature distribution in order to produce a computed numerical integration to predict burn depth.

Lawton's computer model of his adjustment to Henriques (Ref 8) was chosen by the Royal Navy as the way forward. He was asked to produce a computer model to predict HD 1.3 quantity-distances based on his original model and to validate it against the criterion of "Pain Threshold" as recommended by Baker et al.

Erythema (skin reddening) was discarded as the criterion because it varies markedly between types of human skin. People with pigmented skin would feel pain before erythema became obvious.

The validation was to take the form of a report based on a series of test propellant burns sponsored by the Royal Navy.

Test Program

The test program is in four phases:

> Phase 1. The burning of loose propellant in the open to produce unmasked radiation from large flames (expected to produce the worst case thermal irradiation).
>
> Phase 2. The burning of boxed propellant in the open.
>
> Phase 3. The burning of loose and boxed propellant in a confining structure with an opening to induce "jetting".
>
> Phase 4. The burning of propellant in a fully closed structure to induce a fireball.

Phases 1, 2 and 3 have been completed and Phase 4 is awaiting completion. The data from Phase 1 has been analysed by Lawton and his report (Ref 9) validates both his computer model of his adjustment to Henriques and his consequent model to predict quantity-distances.

Phase 1 Test Described - Burns Of Loose Unconfined Propellant

The propellant used was the slow burning triple based slotted tubestick MNLF 2P/S 168-048. It was burned in quantities of 0.5, 1.0, 2.0, 4.0 and 8.0 tonnes.

The first phase test layout comprised three radiating instrumentation arms centred on the fire hearth and spaced 120 degrees apart.

Commercial "Rhopoint" heat flux sensors were positioned along the arms at distances 0.6R, 0.8R, 1.0R and 1.2R away from the centre of the fires where R is the predicted pain threshold

distance. The areas under the recorded flux/time curves were used to produce heat doses.

Flame sizes and colours were recorded in real time using two video cameras calibrated for distance, one upwind and the other across wind.

Optical pyrometers were used to measure flame temperatures.
Site air temperatures and wind speed and direction were recorded for each test fire.

Summary Of Lawton's Report On Phase 1 (Ref 9)

It was found that the flame was turbulent at 1 tonne and above and that it could be modelled fairly accurately as a "flame tube". Around 0.5 tonne the flame was thought to be laminar. (Further trials work in the weight range 100-800kg has been added to later phases to investigate this.)

The combustion rate was confirmed as fairly constant, being dependent largely on propellant grain shape and size. Burns lasted about 27 seconds. The rate did vary directly but slightly with propellant weight by an exponential factor of 0.07.

Flame height and size in the turbulent flame zone could be predicted.

There was correlation between the predicted and the observed heat doses at the gauges so a valid quantity-distance model could be produced.

The report contained Lawton's resultant computer model, both on disk and listed. It included a data input file covering all the parameters describing the thermal properties of the propellant being used. Using the model it is interesting to note theoretically that if a faster burning propellant had been used the heat doses received would have been less due to a lesser exposure time. For the same energy a faster burning propellant is safer than a slower one. The selection of MNLF for the validation tests as a slow burning propellant was a good worst case.

Conclusions On Lawton's Report

The Royal Navy considers that Lawton's HD 1.3 quantity-distance model is valid as a predictive tool for burns of loose propellant in the open in the weight range 1-8 tonnes using pain threshold as the criterion. The model also offers 1st, 2nd and 3rd degree burns as optional extra criteria.

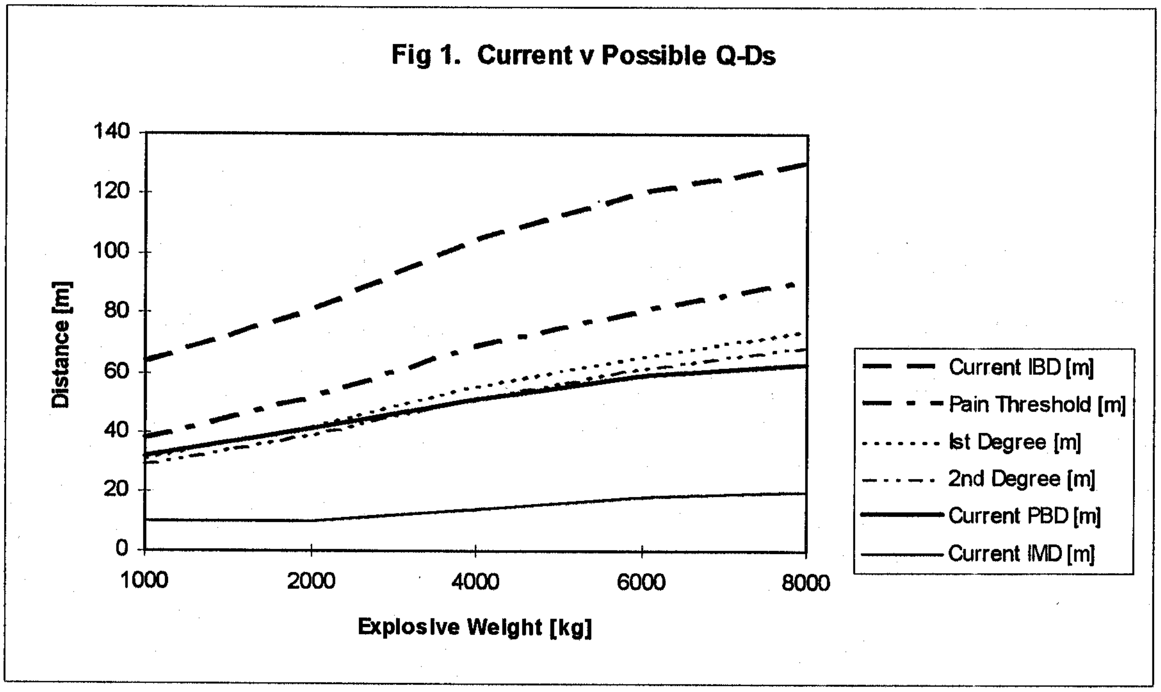

FIG1. CURRENT V POSSIBLE Q-Ds

Using Figure 1 to compare pain threshold distances with existing quantity-distances. it will be noted that:

Pain threshold distances are much shorter than those for Inhabited Building Distances (the public).

Workers at current Process Building Distances would experience pain up to about 1500kg after which they would experience 1st degree burns up to about 3500kg and 2nd degree burns thereafter.

Inter-Magazine Distances could be used instead of Process Building Distances if workers are in heat shadow.

Early Indications From Other Completed Tests

Despite Phases 2 and 3 being completed but not yet analysed, there are early indications from some of their data.

The hazard of thermal irradiation from unconfined boxed propellant is likely to be less than that for loose propellant.

Flame jets approximately 45m long were created from confined fires of up to 4 tonnes. The

irradiation from the jets was less than from unconfined loose propellant. Eventual quantity-distances will be biassed in the direction of the jet and as yet we don’t know if the distances in that direction will be longer than for general unconfined burning.

Of interest to those who design explosive buildings, the confined fires were in a strong building with one vent. The vent area was varied to achieve the greatest length jet possible. There was a limit to the smallness of the ratio of vent area to propellant weight. At the limit no matter what practicible strengthening the building was given it failed when internal quasi-static pressure approached 7 kPa or 1 psi. Early opinion is that this was because the obvious and massive vibration created by the gases speeding through the vent shook the building apart. The test firings were dogged by constant rebuilds.

Relevance Of Work To The Royal Navy

All this test work is against the assumption of a massive fire event, that is an HD 1.3 event, in Royal Naval depots. Although the Navy has a significant amount of ammunition classed HD 1.3 a lot of it comprises propellant or pyrotechnic mixes confined in a munition in inner packs which in turn are in outer packs. A magazine storing munitions configured this way should not give rise to a mass fire event. The likely outcome would be a fire with sporadic pressure explosions associated with subsonic projections. In other words in a fire the ammunition would behave as Non-HE HD 1.2 explosives.

References:

1. DE Jarrett, “Derivation of the British Explosives Safety Distances”, Annals of the New York Academy of Sciences, Volume 152, Article 1, October 1968.

2. Glasstone, “Effects of Nuclear Weapons”, USAEC, 1957.

3. WE Baker, PA Cox, PS Westine, JJ Kulesz, RA Strehlow, “Explosion Hazards and Evaluation”, Elsevier Scientific Publishing, 1983, ISBN 0-444-42094-0 (Vol 5) and ISBN 0-444-41756-7 (Series).

4. K Buettner, “Effects of Extreme Heat On Man”, Journal of the American Medical Association”, No 144, pages 732-738, October 1950.

5. AM Stoll & LC Greene, “Relationship Between Pain and Tissue Damage Due To Thermal Irradiation”, Journal of Applied Physiology, 14, 3, May 1959, pages 372-382.

6. JB Perkins, HE Pearse, HD Kingsley, “Studies on Flash Burns: The Relation of Time and Intensity of Applied Thermal Radiation to the Severity of Burns”, Atomic Energy Report UR 217, University of Rochester, Rochester, NY, 1952.

7. FC Henriques, “Studies of Thermal Injury: The Predictability and the Significance of Thermally Induced Rate Processes Leading to Irreversible Epidermal Injury”, Archives of Pathology, 43, 5 May 1947, Pages 489-502.

8. B Lawton, “Skin Burns Behind Defeated Armour”, 14th Symposium on Ballistics, Quebec, 1993.

9. B Lawton, “Flame Geometry, Burn Time, Radiation and Skin Burns Resulting from Propellant Fires”, Royal Military College of Science, July 1993. (Available from the Defence Research Information Centre, Kentigern House, 65 Brown St, Glasgow, G2 8EX, UK, quoting Reference Number BR 322223.)